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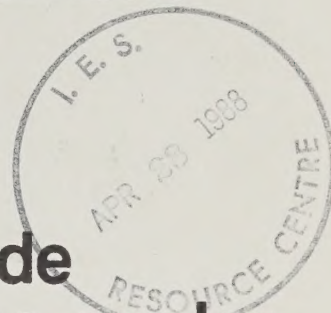


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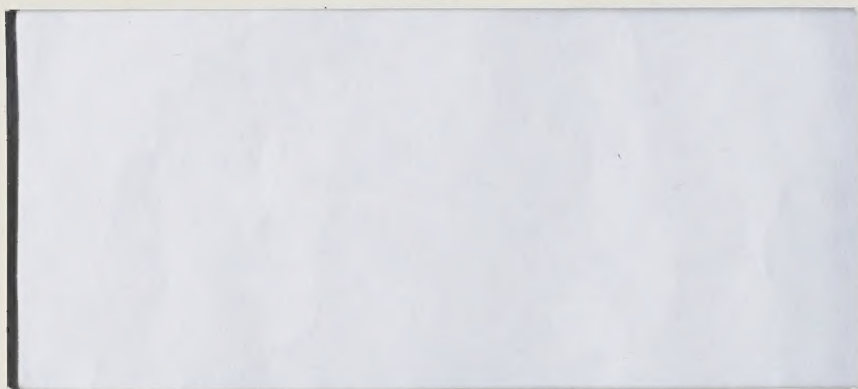
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J. Marsalek¹ and H.O. Schroeter²

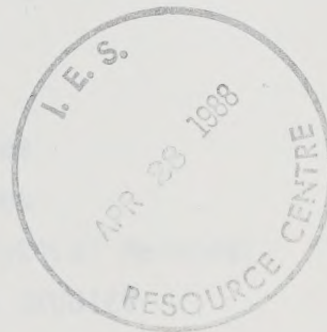
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by

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1.0 INTRODUCTION

Concerns about adverse effects of toxic substances on the environment and human health have increased in recent years. Such concerns are further heightened by the widespread distribution of toxics in the environment and by the bioaccumulation of many toxics and their passage through the food chain in increasing concentrations. Consequently, numerous studies of toxics in the environment have been undertaken during the last 10 years.

Since 1974, the Water Quality Board has been reporting on Great Lakes water quality to the International Joint Commission (IJC). IJC noted that many pollutional problems have been repeatedly reported for certain areas which have then been identified by IJC as "areas of concern". Several such areas of concern which are characterized by environmental degradation and some impairment of beneficial water use caused by toxic substances, have been found in the immediate vicinity of urban areas. Such areas of concern include the St. Clair River (Ontario and Michigan), the Niagara River (New York and Ontario), Hamilton Harbour (Ontario), and St. Lawrence River (New York and Ontario). It is conceivable that similar problems may exist in other locations but on a much smaller scale.

The concerns reported by IJC for the above areas are related to toxic substances pollution. These concerns are briefly summarized below (5).

The St. Clair River - sediments along the Ontario shoreline are contaminated with PCB's, chromium, copper, lead, mercury and zinc. Such contamination slows recovery of benthic fauna adjacent to and downstream of the petroleum and petrochemical complexes in the area.

Fish contamination was also noted. Other significant contaminants include bacteria and phenol.

The Niagara River - water, sediment and fish from the Tonawanda Channel of the Niagara River are severely contaminated. Extensive contamination was also found in the lower Niagara River. Almost all sediments from the Tonawanda Channel are heavily contaminated with conventional pollutants, heavy metals, and PCB's in excess of acceptable concentrations for open-water disposal of dredged materials. High contamination by other organic substances of industrial origin was also found in many samples. Sediments from the lower Niagara River were generally contaminated by heavy metals. Many organic substances have been found in sediment and water samples collected in the river near industrial landfills.

Hamilton Harbour - sediments are heavily contaminated with nutrients, several heavy metals and PCB's. Such contamination is particularly significant in the area adjacent to municipal and industrial discharge points. Organochlorine pesticides have been detected in sediments. Oxygen demand from municipal and industrial discharges, sediments, and algal decay lower hypolimnetic dissolved oxygen levels, especially in the summer, thus reducing the suitability of the harbour as a fish habitat.

The St. Lawrence River - some contamination of fish by mercury and PCB's has been reported. Sediment samples from the area are contaminated with nutrients, heavy metals, oil and grease, and PCB's. Increased levels of phosphorus, total phenolics, certain heavy metals, PCB's, and two organochlorine pesticides were observed in the river.

IJC also identified the sources of toxics in the areas of concern and classified these sources into the following six categories:

Municipal and industrial discharges

Waste disposal sites

Combined sewer overflows

Urban land runoff

Agricultural land runoff, and

In-place pollutants.

The report that follows investigates one of these six sources - urban land runoff.

The primary objective of this study was to estimate the annual loadings of selected toxics in urban land runoff in the Canadian Great Lakes Basin. Such loadings are obtained as the sum of two loading components - the component carried by runoff water and that carried by urban sediments and solids. To estimate both components, the annual volume of runoff and the loading of solids need to be calculated and the corresponding toxics concentrations established from field observations. The annual loadings are then obtained by multiplying the annual runoff volume and the annual solids loading by the corresponding concentration.

The annual loadings presented later in this report can be used for an expedient comparative assessment of various sources of toxics, recognizing the inherent uncertainties in the loadings. For example, the results obtained in the second phase of this study were used in comparisons of urban runoff loadings with the point-source loadings in the Niagara area (14). It was noted that urban runoff contributed from 60% to 90% of the point-source loadings of PCB's,

copper, lead and zinc. For two polyaromatic hydrocarbons, pyrene and fluoranthene, the runoff loadings exceeded those from point-sources 21 and 12 times, respectively. For the remaining six substances evaluated, the runoff loadings represented from 6% to 34% of the point-source loadings. It should be emphasized that the above results are site specific and not transferable to other areas.

The study was undertaken in three phases - the first phase represented detailed investigations of toxics in Cornwall (21,22), the second stage focussed on toxics loadings in the Niagara area (9) and field investigations in 12 urban centres, and the third phase, which is described in this report, dealt with the processing of the earlier obtained data and calculations of the annual toxics loadings.

It should be mentioned that the combined sewer overflows have not been specifically evaluated in this study. The loadings in overflows represent the sum of loadings in urban runoff (discussed here) and loadings in the municipal sewage contained in overflows. The later loading can be evaluated using information on toxics in municipal wastes. Such information was not available during the preparation of this report. According to Waller and Novak (18,19), the overflows represent about 2% of the annual sanitary sewage discharge. Thus the loadings in overflows, originating in sanitary sewage (excluding surface runoff) could be expediently evaluated from information on toxics loadings in raw sanitary sewage.

2.0 STUDY AREA

The study area represents urban areas in the Canadian Great Lakes Basin. The basin was divided into five sub-basins corresponding to Lakes Erie, Huron, Ontario, St. Clair and Superior.

2.1 Urban Population

In each sub-basin, urban centres have been identified and urban drainage areas estimated from urban population. For this purpose, the 1981 Population Census data were used.

Urban population areas are defined by Statistics Canada (12) as areas having a population concentration of 1,000 or more and a population density greater than 4 persons per ha. This definition was found inappropriate in this study for two major reasons. Firstly, population concentrations in the range from 1000 to 5000 may be pertinent to areas which do not have fully developed urban drainage systems (e.g., paved streets and storm sewers). These areas are predominantly rural with respect to the generation of runoff (e.g., high infiltration rates). Secondly, the density criterion is somewhat restrictive and may exclude many highly urbanized areas with low population densities which are calculated for areas defined by political municipal boundaries (11). In recent years, several heavily urbanized centres have expanded their boundaries by annexing adjacent lands (e.g., same-name townships), and therefore the overall population density has been reduced to well below 4 persons/ha. For example, the municipalities of Dunnville, Halton Hills (formerly Acton) and Nanticoke have populations in excess of 10,000 but population densities less than 1.5 persons/ha.

Consequently, for the purpose of this study, the areas contributing significant amounts of urban runoff and solids were defined as follows (11):

- (a) All urban centres with population greater than 10,000 (regardless of the population density)
- (b) Urban centres with population from 5,000 to 10,000 and the density greater than 4 persons/hectare.

Using these criteria, 119 urban centres with the total population of almost 6,300,000 persons have been identified in the study area. All the centres are listed in the Appendix (Tables A.1 - A.5) and the summary of the sub-basin populations is given in Table 1.

2.2 Urban Land Use Distribution

The hydrologic characteristics and surface water quality are influenced by basin population and land use activities which are characteristic for various types of land use. For this reason, it was necessary to classify urban land into several standard land use categories: residential, commercial, industrial and open land. Residential land use generally includes institutional land use. The open land category includes large recreational areas as well as undeveloped areas within municipal boundaries.

In the next step, it was required to establish individual areas for each land use category. In the absence of actual data, it was decided to establish such areas from the relationships between the land use areas and populations which were developed by the Community Planning Branch of the Province of Ontario (3). These relationships are listed below.

$$A_r = 0.11 (\text{POP})^{0.847} \quad r = 0.98 \quad (1)$$

$$A_c = 0.019 (\text{POP})^{0.788} \quad r = 0.95 \quad (2)$$

$$A_i = 0.013 (\text{POP})^{0.944} \quad r = 0.93 \quad (3)$$

$$A_o = A_t - (A_r + A_c + A_i) \quad (4)$$

where A_r , A_c , A_i , A_o and A_t represent the residential, commercial, industrial, open and total areas, respectively, in ha, r is the correlation coefficient, and POP denotes population. Comparisons of the land use distributions calculated from the above equations with the distributions reported for several Ontario cities (13) indicated good agreement except for industrial areas. For larger populations ($> 10,000$), industrial areas determined from Eq. (3) appeared to be much too large, and consequently, A_i was computed as

$$A_i = 0.25 A_r \quad (5)$$

In a few cases, the application of Eq. (4) produced negative values of A_o . This occurred when the sum of the residential, commercial, and industrial areas calculated from Eqs. (1) to (4) exceeded the total area A_t available from the Statistics Canada (12). This discrepancy follows from the empirical nature of Eqs. (1) to (4) and the fact that these expressions were derived from earlier land use data which may differ from the current data. Nevertheless, expressions (1) to (4) represented the best readily available approach to obtain land use areas. It was felt that these expressions would yield conservative estimates as the density of development increased in recent years.

When the calculated open land area A_o was negative, A_o was simply set to zero and the other land areas were proportionally

reduced so that their sum would equal the total area. Such adjustments are described by the following equations:

$$A'_r = (A_r/A) A'_t \quad (6)$$

$$A'_c = (A_c/A) A'_t \quad \text{for } A' > A_t \quad (7)$$

$$A'_i = (A_i/A) A'_t \quad (8)$$

$$\text{with } A = A_r + A_c + A_i$$

where A_r , A_c , and A_i were determined from Eqs. (1) to (3).

2.3 Annual Precipitation Data

The annual precipitation data were obtained from the Canadian Climate Normals, 1951 to 1980 (2). These data represent the total mean annual precipitation from rainfall and snowmelt (water equivalent) for a thirty year period. The return interval of the mean annual precipitation is about two years.

For most urban centres, precipitation data were readily available, however, in some instances, the annual precipitation had to be estimated from data for neighbouring areas using the Thiessen polygon technique described in standard hydrology texts (17). In some urban centres, precipitation data were available from more than one station. In this situation, the data from all stations were averaged to yield the annual precipitation for the given urban centre. The annual precipitation data for each urban area considered are given in the Appendix.

3.0 FIELD PROGRAM

The field program represented a major effort in the study of toxics in urban runoff in the Great Lakes Basin. This program was operated from September 1980 to December 1982. The main objective of the program was to collect representative samples of urban runoff and sediment from various sources. Such a program was designed on the basis of understanding of pollutant pathways in urban areas as obtained from the earlier studies and the literature.

Various sources and pathways of urban runoff pollutants are described first, followed by details of the field program procedures.

3.1 Sources and Pathways of Urban Runoff Pollutants

In order to design an effective sampling program for investigations of urban land runoff pollution, it is necessary first to examine the sources and pathways of runoff pollutants in urban areas. Although such processes are rather complex, considerable simplifications are acceptable for the purpose of this study. Detailed discussion follows.

The sources of toxics in urban runoff are quite numerous and include atmospheric sources as well as sources related to land use activities. The atmospheric sources may be of local or remote origin and contribute to runoff pollution through both dry and wet precipitation.

Dry precipitation results in accumulation of particle deposits on the catchment surface and these deposits are then washed off during the periods of runoff. To investigate this source and

possible source controls, it is of interest to collect samples of street surface deposits. Their composition may vary depending on the local sources of pollutants and the direction and effectiveness of their transport. Pollutants from remote sources are imported to the catchment and their characteristics do not correlate well with local land use and other conditions. On the other hand, local air pollution also contributes to pollutant accumulation and such a contribution will be related to the distance from local sources and prevailing wind directions.

Another source of toxics is wet precipitation. It has been noted in the literature that many toxics are transported over large distances and reach the ground in the form of wet precipitation. Thus such substances are imported and do not relate well to the local land use. Again, it is of interest to sample this source by collecting rainwater samples. Findings of the first phase (21) indicated only minor variations in concentrations of toxics in rainwater within an urban area.

Other sources of toxics are those related to land use activities. Such sources include applications of pesticides in urban areas, release of toxics during industrial operations, spills, etc. Such activities determine the composition of runoff in the affected areas and seem to be particularly pronounced in industrial areas. In most cases, toxics accumulate on the catchment surface and are subsequently washed off during wet weather. To sample these sources, one needs to collect samples of surface deposits and stormwater.

During the periods of runoff, the rainwater, which is already contaminated by toxics, reaches the catchment surface and washes off and transports substances accumulated on the catchment surface. Such processes are particularly intense on impervious parts

of the catchment where practically all the rainwater runs off and the flow velocities and the resulting transport rates are fairly high. On pervious areas, the rainfall rate is smaller than the rate of losses (i.e., infiltration and surface storage) for long segments for the storm and, consequently, the rate and volume of runoff are rather small. Exceptionally, during rain storms of high intensity, or in the case of poorly drained soils, pervious parts of the catchment may contribute appreciably to the catchment runoff. Thus the monitoring activities should concentrate on impervious areas whose extent is closely related to land use and the population density.

The rate of pollutant transport during individual storms is not generally constant, but varies depending on the runoff rate, the amount of pollutants remaining on the catchment surface, and some other factors. In some catchments, the so-called first-flush was reported for conventional pollutants. This term is used to describe pollutographs which exhibit the highest concentrations during the early parts (more or less coinciding with the rising hydrograph limb) of runoff events when the greatest quantities of pollutants are available on the catchment surface. Considering the high costs of toxics analyses, it is infeasible to collect sequential samples and to characterize toxic concentration variations during storms. If the primary interest is the substance loading, it is preferable to collect composite samples for individual events. Ideally, the sample composition should be flow proportional.

Earlier studies indicated (9,21) that toxics are associated with urban sediment in concentrations two to three orders of magnitude higher than those found in stormwater. It is, therefore, desirable to sample both urban sediment and stormwater. Urban sediment samples can be obtained by collecting street deposits samples or by filtering out

solids which are transported by stormwater. Stormwater samples may be collected in various transport elements of the drainage system.

Thus it follows from the above discussion that the sampling program should be designed on the basis of the following considerations:

Sediment as well as liquid samples should be collected in areas with various urban land use (with emphasis on industrial land use).

Sediment samples should be collected during both dry and wet periods.

Samples of stormwater should be collected as flow-proportional composite samples.

3.2 Selection of Sampling Sites

The selection of sampling sites was influenced by the distribution of urban population in the basin and the need to co-ordinate field activities with the work of other collaborating agencies. A listing of sampling locations is given in Table 2.

It follows from Table 2 that field samples were collected at 81 sites in the following 12 urban centres:

Burlington
Cornwall
Fort Erie
Guelph

Hamilton
Kingston
Niagara Falls
Ottawa
Sarnia
Stratford
Toronto, and
Welland.

In individual urban centres, samples were collected at several sites with various land use. The land use types sampled included commercial, industrial, institutional and residential land use. The number of events sampled at each site varied from 1 to 15. The events sampled represented either runoff events, or dry weather periods during which solids accumulated on the catchment surface. In most cases, the sampling was limited to surface runoff and street surface solids - the major sources of pollutants carried by urban runoff. To investigate various sources of toxic substances, special samples of rainwater, roof runoff, stormwater (in sewers) and suspended solids in stormwater were also collected. At two sites, a few grab samples of road snow and ice were also collected. Further studies of snowmelt quality were prevented by the study timing.

3.3 Sample Collection Methods

Flow measurement and sampling methods for studies of urban runoff have been established for conventional pollutants. In such studies, the pollutant concentrations are fairly high and the sample cross-contamination is limited. The methodology for monitoring of toxics in urban runoff is not well established and many procedures and devices used in this study were developed on the basis of general

recommendations of the U.S. Environmental Protection Agency (15) and the Water Quality Branch of Inland Waters Directorate. It should also be emphasized that the study budget and schedule did not allow acquisition of sophisticated equipment. Descriptions of various sample gathering methods follow.

Sewer Inlet Sampler

The sewer inlet sampler is a simple custom made device which serves for collection of surface runoff samples. Basically, the sampler consists of a large stainless steel funnel, which fits under the inlet grate, and of a sample container. The funnel diverts a small fraction of the total inflow via a teflon tube into the sample container which is either a glass bottle or a stainless steel vessel. The bottles used for storage had a capacity of 22 litres, the stainless steel vessel had a capacity of 15 litres.

The sewer inlet samplers were used to collect about 70% of all water samples.

Automatic Wastewater Samplers

Some stormwater samples were collected by means of automatic wastewater samplers which were operated in the sequential mode. Sequential samples were then composed proportionally to the flow rates measured by an electromagnetic flow recorder (March - McBirney Model 265). In some other installations, a peristaltic pump was used to collect samples.

The automatic sampler originally employed was the ISCO Model 2100 which has been recommended for toxics monitoring in the U.S.A. It is a sequential sampler which collects samples by means of

a peristaltic pump. To avoid sample contamination, all the internal plumbing is made of stainless steel or teflon, with the exception of a short piece (0.6 m) of tubing in the peristaltic pump. This tubing must be fairly flexible for good pump operation and, consequently, a medical-grade silicone rubber tubing is used for this purpose. The particular brand used in the ISCO sampler is referred to as the Dow Corning medical grade Silastic. The sampler manufacturer states that this brand of tubing will not contribute any organic material to samples (6). In field operation, up to 24 sequential samples of stormwater were collected and used to produce a single flow-proportional composite sample.

In a later phase of the study, another automatic sampler, the Sigmamotor 6201, was also used. A standard Model 6201 was modified for the monitoring of toxics in a similar way as done in the ISCO sampler. Again a medical-grade silicone rubber tubing was used in the sampler peristaltic pump. The sample distribution system which could contaminate samples was bypassed using teflon tubing and samples were composed in a single glass container.

Concerns about the possible contamination of samples by various types of tubing led the Environmental Protection Service, Ontario Region, to initiate tests of three types of tubing (4). The test results were released in June, 1983, thus too late to be implemented in this study. These results indicated that, for the severe test conditions employed, some sample contamination may be caused by both silicone and tygon tubing. It should be mentioned that the silicone tubing has not been properly identified in the draft report (4) and subsequent enquiries have not clarified the tubing origin. In particular, two substances, ethoxy butoxy ethanol and dichlorobenzoic acid, appeared on the spectrum printout in an area where certain priority pollutant could appear. If such priority

pollutants were of low concentration, they would be masked by the leached substances. It was recommended to pretreat the silicone rubber tubing by flushing with deionized water at pH2, for 16 hours prior to the use, to minimize contamination.

Although the possibility of sample contamination in automatic samplers with peristaltic pumps cannot be completely discounted, the danger of such contamination can be reduced by using a proper tubing material and by pretreating the tubing. No evidence has been found that the silicone rubber tubing in the ISCO sampler contaminates samples.

After every event, the sampling equipment was cleaned.

Rainwater Collectors

Rainwater was collected at several temporary sites using a set of glass trays with a capacity of 2 litres each.

Collection of Sediment Samples

Two collection methods were used to obtain sediment samples. In the first one, suspended solids samples were obtained by filtration of stormwater samples which were typically collected by means of sewer inlet samplers. Standard laboratory equipment was used to filter stormwater samples. The filtration process was aided by vacuum, or for large volumes, by compressed gas. The filter used was the MILLIPORE type LS with the pore size of 5.0 μm (0.005 mm). To obtain a sufficient quantity of solids, from 5 to 15 litres of stormwater had to be filtered. Filtered solids were placed in glass jars and submitted for analysis.

Samples of street surface sediment were generally collected by dry vacuuming. Collected solids were placed in glass jars and transported to the laboratory for analysis. Some fractions of such samples were further analyzed for particle size distribution.

3.4 Transport and Preservation of Samples

All field samples were removed from sampling devices as soon as possible after the end of the sampled event and placed in transport containers. Glass bottles or jars with their top covered by aluminum foil were used for such a purpose.

In the laboratory, the samples were transferred from transport containers into laboratory bottles, preserved, and submitted for analysis. For organics analyses, two 1-litre samples in glass bottles were submitted. Samples for trace metal analyses were placed in 250 mL plastic bottles and preserved by adding 1 mL of 50% HNO_3 . Samples for mercury analysis were submitted in 100 mL brown glass bottles. Such samples were preserved by adding 1 mL of concentrated H_2SO_4 and 1 mL of 5% potassium dichromate solution (dithizone-extracted).

Sediment samples were delivered in glass jars to the analytical laboratory and subsequently were frozen.

3.5 Cleaning Procedures for Sample Containers

For cleaning sample containers, the procedures recommended by the Water Quality Branch, IWD, Ontario Region, were used. According to these procedures, containers were washed with soap and

hot water, rinsed several times with hot water and then rinsed several times with distilled water. After draining water from the container, it was rinsed two or three times with analytical grade acetone and petroleum ether, followed by two or three rinses with pesticide residue grade ethyl acetate and, finally, the container was rinsed with pesticide residue grade hexane. The volume of each rinse was 2% to 3% of the container volume.

Clean bottles were capped with solvent-washed aluminum foil.

4.0 SAMPLE ANALYSIS

Field samples were delivered to analytical laboratories for detailed and extensive analyses. A list of substances studied is presented first followed by a summary of analytical procedures.

4.1 Toxic Substances Studied

The selection of toxic substances studied was initially based on the U.S. Environmental Protection Agency list of priority pollutants. This list was further modified and the final selection of 51 substances was more or less given by the availability of analytical procedures in the laboratories employed. These substances can be divided into five groups: Polychlorinated biphenyls (PCB's), organo-chlorine pesticides (OCP's), polyaromatic hydrocarbons (PAH's), chlorinated benzenes (CB's) and trace elements (TE).

A detailed listing of substances in individual groups and the detection limits for analyses employed are presented in Table 3. Detailed information on the toxic substances studied can be found in Ref. 16.

4.2 Laboratory Procedures

Sample analyses were done by two analytical laboratories - the Laboratory of the Water Quality Branch of IWD, Ontario Region and by the Analytical Laboratory of the Ontario Ministry of the Environment. Although the use of two laboratories which may employ different analytical procedures is not generally desirable, such a

solution was necessitated by the fact that neither laboratory had a spare capacity to analyze all the samples.

4.2.1 IWD Laboratory Procedures

Details of analytical methods used by the IWD laboratory can be found elsewhere (20). A brief description of general procedures follows.

Trace Elements. Atomic absorption spectroscopy was used for determination of metals in stormwater samples. The main advantages of this technique follow from its ease of operation, sensitivity, and applicability to a large number of metals in a wide variety of waters, including surface water, domestic wastes and industrial wastes. Further details are given in Ref. 20.

Several methods were used to determine total metals and other inorganics in sediments.

Mercury in sediment was determined by cold vapour atomic absorption. Arsenic and selenium were determined by flameless atomic absorption. The remaining analyses were done by means of the bomb digestion method. In this method, the sample decomposition is carried out in a sealed teflon bomb. Sample solutions are then analyzed by atomic absorption spectroscopy. This method was used for cadmium, chromium, cobalt, copper, lead, nickel, selenium and zinc.

Trace Organics. All water samples were extracted using the methylene chloride water extraction method which was described elsewhere (20). The sediment samples were extracted by ultrasonic extraction. Because of high amounts of coextracted interfering

compounds present, an additional clean-up step involving gel permeation chromatography was added. Further information on this procedure, which is not among standard procedures, can be obtained from the IWD laboratory.

The analysis of extracts was performed using gas chromatography. For PCB's and organochlorine pesticides, high resolution gas chromatography with two columns was used. For PAH's and CB's, one column gas chromatography was used. The detectors used were a flame ionization detector for PAH's and an electron capture detector for the remaining substances.

4.2.2 MOE Laboratory Procedures

A description of laboratory procedures was supplied by the MOE laboratory (7,10). Such procedures are summarized below.

Trace Elements

Heavy metals in water samples were analyzed by means of either atomic absorption spectrometers or inductively coupled plasma atomic emission spectrometers. Both types of instruments produce equivalent, unbiased data.

For sediment samples, the samples were first digested with aqua regia and then analyzed using the same instruments as for water samples.

Arsenic and selenium in both water and sediment were determined by first digesting appropriate aliquots with sulphuric,

nitric acid mixture in a hot block to fumes. The digestate was then analyzed by automated hydride generation, flameless atomic absorption.

Trace Organics

Water samples were extracted by the methylene chloride extraction method. Sediment samples were extracted by ultrasonic extraction, referred to as the Sonifier method. Extraction was followed by a cleanup procedure using adsorption chromatography on Florisil.

Sample analysis was done by gas chromatography using Hewlett Packard 5700 series gas chromatographs equipped with electron capture detectors.

4.3 Precision and Accuracy of Analytical Methods

One of the sources of uncertainties in the toxics loadings (presented later) are uncertainties inherent to analytical procedures. Such uncertainties are typically described as precision and accuracy of a particular analytical method. Precision refers to the repeatability of measured values and is expressed as the standard deviation or the coefficient of variation (1). Accuracy is measured by the agreement between the amount of constituent measured and the amount actually present (1). Both precision and accuracy of an analytical method can be evaluated by analyzing samples with known constituent concentrations.

Indications of precision and accuracy of various analytical methods which are employed by the Water Quality Branch (20) are given for selected trace elements and organochlorine pesticides in Tables 4

and 5, respectively. Similar data for chlorinated benzenes, polyaromatic hydrocarbons and PCB's were not available, however, the information provided in Tables 4 and 5 is deemed sufficient for discussion purposes.

It appears from Table 4 that the precision of trace element analyses is rather high and the uncertainties in the reported concentrations do not contribute significantly to the uncertainties in the loadings which are presented later.

The data in Table 5 indicate that the accuracy of trace organics analyses is affected by the extraction procedures. For the lower levels, the average recovery of the substance added is about 90% with deviations of 20%. The corresponding precision is about 40%. As a consequence, appreciable uncertainties may be introduced by the analytical procedures for trace organics and these would be reflected in the loadings which are presented later in the report.

5.0 ANNUAL LOADINGS OF TOXICS SUBSTANCES STUDIED

Field studies of toxic substances in urban runoff indicate that there are two mechanisms for transport of toxics from the catchment surface. The first mechanism is transport by runoff water and the second one is by means of solids suspended in stormwater, or transported as bed load. Thus, the total loading of toxics in urban runoff can be conceptually divided into the loading attributed to the liquid phase and the loading attributed to the solid phase. To estimate such loadings, on an annual basis, it is required to estimate the annual runoff volume and the annual loading of solids. Such quantities are then multiplied by mean toxics concentrations to obtain annual loadings of toxics.

The material presented in this section starts with the presentation of mean concentrations of toxics in runoff water and solids, followed by calculations of the annual volume of runoff and the solids loading, and the calculation of annual loadings of toxic substances.

5.1 Estimates of Mean Concentrations of Toxic Substances

Estimates of mean concentrations were made for all the substances studied. Such estimates involve appreciable uncertainties which were created by the data below the analytical detection limits. At present, there are no established procedures for the treatment of such data. A simple approach (8) was used to account for the uncertainties by providing three estimates of the mean concentration referred to as lower, upper and best. The lower estimate, C_{min} was calculated as

$$C_{\min} = \frac{1}{n} \sum_{k=1}^n C'_k \quad \begin{aligned} C'_k &= 0 \quad \text{if } C_k < C_L \\ C'_k &= C_k \quad \text{if } C_k \geq C_L \end{aligned} \quad (9)$$

where n is the number of samples tested, C' denotes the concentration used in the summation for sample k , C is the reported concentration of sample k , and C_L is the detection limit for sample k . The upper estimate, $C_{\max}$ was computed as

$$C_{\max} = \frac{1}{n} \sum_{k=1}^n C'_k \quad \begin{aligned} C'_k &= C_L \quad \text{if } C_k < C_L \\ C'_k &= C_k \quad \text{if } C_k \geq C_L \end{aligned} \quad (10)$$

The best estimate, C_{be} is given by

$$C_{be} = \frac{1}{n} \sum_{k=1}^n C'_k \quad \begin{aligned} C'_k &= 0.5 C_L \quad \text{if } C_k < C_L \\ C'_k &= C_k \quad \text{if } C_k \geq C_L \end{aligned} \quad (11)$$

If all concentrations are greater than the detection limit, then all three estimates will be equal. Mean concentration estimates were produced for both runoff water and sediment samples.

Large uncertainties in concentration data and the relatively small number of samples with concentrations above the detection limits did not justify the division of concentration data into subcategories according to land use. Thus, the mean concentrations given in Tables 6 to 9 represent arithmetic means of all sampled concentrations

with the values below the detection limit adjusted as per Eq. (11). These tables also include the total number of samples and frequency of concentrations above the detection limit.

The lower and upper estimates of mean concentrations were determined using eqs. (9) and (11) and listed in the Appendix in Tables A.6 - A.9. Comparisons of lower and upper estimates of mean concentrations indicate uncertainties caused by the data below the detection limits. Such uncertainties were found significant only for polyaromatic hydrocarbons. The relatively high detection limits and low frequencies of detection contributed to high uncertainties in estimates of mean concentrations of PAH's. Such uncertainties are then reflected in the loading estimated as discussed earlier.

All toxic concentration data obtained in this study are available on request from the Hydraulics Division, National Water Research Institute, 867 Lakeshore Road, Burlington, Ontario, L7R 4A6.

5.2 Annual Runoff Volumes and Solids Loadings

As background information for calculations of annual loadings of toxics, it was necessary to determine the annual runoff volumes and solids loadings.

5.2.1 Annual Urban Runoff Volumes

Annual urban runoff volumes were calculated from the annual precipitation depth, the contributing area, and the volumetric runoff coefficients which were established for various land use. Typical values of runoff coefficients (17) as well as the values adopted in this study are given in Table 10. The adopted values were selected somewhat conservatively to reflect annual volumes of runoff rather than single event conditions.

The annual runoff volume, R in m^3 , was then computed as

$$R = P \sum_{j=1}^4 C_j A_j \quad (12)$$

where P is the annual precipitation in m , C is the runoff coefficient, A is the contributing area in m^2 , and j denotes the land use type.

The annual runoff volumes were calculated for 119 urban centres in the Great Lakes Basin and summarized in the Appendix (Tables A.1 - A.5). The total runoff volumes for each sub-basin are listed in Table 11.

It is obvious from Table 11 that the undeveloped parts of urban centres contribute from 65% to 87% of the total runoff volume, in spite of the relatively low runoff coefficient. Because these undeveloped parts generally preserve their rural character and the corresponding runoff and water quality processes will differ from those in developed parts of urban centres, it was decided to omit the open land category in calculation of the best estimates of toxics loadings. For completeness, the results of loading calculations including the open land runoff are given in the Appendix (Tables A.11 - A.14).

5.2.2 Annual Solids Loadings

Solids or sediment have been found to be an effective medium for the transport of toxic substances in urban runoff. Consequently, it was necessary to estimate the annual discharge of solids in the Great Lakes Basin, and a simple procedure based on annual unit loadings was used (8). The annual loading of solids in urban runoff was computed as follows:

$$S = \sum_{j=1}^4 U_j A_j \quad (13)$$

where S is the annual solids discharge from runoff in kg, U denotes the annual unit load of solids in kg/ha, and j denotes land use type. The unit solids loadings in Table 12 were adopted from Ref. 8. The solids loadings for each urban centre were calculated and tabulated in the Appendix (Tables A.3 - A.5). In Table 13, the annual solids loadings for each Great Lakes sub-basin are summarized.

As explained earlier for runoff volumes, the solids loadings for the open land category were omitted in the calculation of best loading estimates, but included in the Appendix in Tables A.11 - A.14. For solids, the open land category contributed from 17% to 42% of the total basin loading.

5.3 Annual Toxic Substance Loadings

5.3.1 Computational Procedure

The annual loadings of toxic substances were calculated as follows:

$$L_i = R C_{wi} + S C_{si} \quad (14)$$

where L is the annual loading in kg, C_w is the mean concentration of the substance in water, C_s is the mean concentration of the substance in solids, and i denotes the various toxic substances. The values of C_w and C_s were obtained from Tables 6 through 9.

The annual runoff volume R and the solids loading S were derived for the fully developed part of urban centres including the residential, commercial and industrial land.

5.3.2 Summary of Results

The total annual loadings of the 51 toxic pollutants were computed for each Great Lakes sub-basin and the best estimates of such loadings are summarized in Tables 14 through 17. The annual loading estimates based on the lower and upper estimates of mean concentrations are presented in the Appendix in Table A.10. It is evident from Table A.10 that the various loading estimates vary very little with the exception of PAH's loadings. Because the predictions were based on mean annual precipitation, it should be noted that the computed loadings may be exceeded in any given year.

Finally, the toxic loadings for all the land under municipal jurisdiction were also calculated and presented in the Appendix in Tables A.11 -A.14. In these calculations, the contributions of open land to the annual runoff and solids production were included and, consequently, the calculated loadings exceed those for fully developed urban land (Tables 14 - 17).

6.0 DISCUSSION

Estimations of annual loadings of toxic substances represented a fairly extensive task which had to be accomplished within the limited time frame, analytical support and budget of the study. Consequently, the emphasis was placed on relatively simple procedures which introduced some uncertainties into the estimated loadings. It was felt, however, that such uncertainties are acceptable at the first level of estimation where the loadings are produced mainly for the purpose of comparison of various sources. In cases where the differences among various source loadings exceed significantly uncertainties in loading estimates, further improvements in the accuracy of loading estimates may not be required. If the differences among various source loadings are relatively small, more detailed evaluations of loadings may be justified to reduce the uncertainties. In the following, the main sources of uncertainties in loadings of toxics in urban runoff are discussed and suggestions for further improvements are made.

The total loading of a particular toxic substance in urban runoff was taken here as the sum of loadings transported by water and solids which can be expressed as

$$L = \bar{C}_w P \sum_{j=1}^n C_j A_j + \bar{C}_s \sum_{j=1}^n U_j A_j \quad (13)$$

where $\bar{C}_w$ and $\bar{C}_s$ represent mean concentrations of the toxic substance in water and sediment respectively. Thus, the following sources of uncertainty can be identified:

Precision and accuracy of analysis of water and sediment samples

Representativeness of samples collected

Annual precipitation

Annual runoff coefficient

Land use area estimates

Annual unit solids loadings

Detailed discussions of sources of uncertainties follow.

Precision and accuracy of analysis of water and sediment samples. Information on precision and accuracy of analytical methods was presented earlier in Section 4.3. The best accuracy and precision were reported for trace elements in both water and sediment samples. In this case, the uncertainties in the analytical results are fairly low and do not contribute significantly to uncertainties in loading estimates. The highest uncertainties in analytical results were noticed for PAH's. Relatively high detection limits and concurrent low frequencies of occurrence contribute significantly to the uncertainties in PAH's loadings. It would be desirable to lower the PAH's detection limits, if further work is required. For the remaining groups of substances, organochlorine pesticides and chlorinated benzenes, the precision and accuracy of analytical procedures was deemed adequate.

Representativeness of Samples Collected. Cost considerations and the limited analytical support available controlled the overall number of samples that were collected during the field program. Such limitations lead to the question to what extent the reported mean concentrations represent the actual conditions in the Great Lakes Basin. The sampling program was designed to produce mean values of toxics concentrations by collecting flow-proportional

composite samples of entire runoff events. Similarly, the sediment samples collected represented solids accumulations over extended dry periods. Such procedures would lead to smoothening out of large variations in instantaneous concentrations. It is possible, however, that the mean concentrations employed do not reflect contributions of some strong local sources. Such contribution can be evaluated only through local field sampling as done in the earlier phases of this study in Cornwall and the Niagara area.

Annual Precipitation. Annual precipitation data are available from the Atmospheric Environment Service. The data used in this study were found adequate for the calculation of loadings and no further evaluations or improvements of these data are needed.

Annual Runoff Coefficient. The annual runoff coefficient indicates what fraction of the annual precipitation is converted into runoff. The overall runoff coefficient which was used in this study for fully developed urban areas was 0.45. Such a value seems to be realistic. Further improvements would be possible only by accounting for local hydrologic conditions (e.g., hydrologic soil groups) and applying hydrological modelling. Two possible approaches were demonstrating in the earlier phases of the study - applications of the STORM model in Cornwall (21) and the Soil Conservation Method in the Niagara area (9).

Land Use Area Estimates. Areas of various types of urban land use were estimated, by regression relationships, from the urban population. Such a procedure involves appreciable uncertainties which will be reflected in the calculated loadings. Further improvements would be possible through a tedious collection of land use data from all the urban centres considered in the study. It should be further emphasized that the loading estimates in this report correspond to

fully developed parts of urban centres which are characterized by residential, commercial and industrial land use. Possible contributions from open (undeveloped) land under municipal jurisdiction were excluded.

Annual Unit Solids Loadings. These unit loadings were used to calculate the annual loading of solids and the corresponding loading of Toxics. The uncertainties in the unit loadings are fairly appreciable and will be reflected in the loading of solids. It was noted that, typically, 3/4 of the annual total loading of toxics were carried by water and only one quarter was carried by solids. This distribution will reduce the propagation of uncertainties in unit solids loadings to the annual total loadings of toxics. Further improvements would be possible by verifications of calculations of annual solids loadings by other approaches (9).

Finally, the uncertainties in the presented annual loadings of toxic substances were estimated in the range from $\pm 50\%$ to $\pm 80\%$. The lower limit applies to trace elements and the upper limit to trace organics.

7.0 SUMMARY

The annual loadings of 51 persistent toxic substances in urban runoff in the Canadian Great Lakes Basin have been estimated from field data on toxics concentrations and calculated annual volumes of runoff and solids loadings. It was estimated that the total runoff from fully developed parts of urban centres in the basin is almost 600 million m³ annually. In accord with the population distribution, the highest volume is produced in the Lake Ontario sub-basin (62% of the total) followed by the sub-basins of Lakes Erie (15%), Huron (12.5%), St. Clair (9.1%), and Superior (1.5%). It was further estimated that this volume of runoff transports about 70,000 tonnes of solids annually. Open (undeveloped) land under municipal control may contribute another 1650 million m³ of runoff and 20,000 tonnes of solids annually.

The field studies of toxic substances in 12 Ontario communities indicate that all the substances studied can be found, at levels above the common detection limits, in urban runoff and solids carried by runoff. The frequencies of such detections varied widely depending on the media sampled and substance under consideration. In general, the frequencies of detection above the detection limits for sediment samples were about 50% higher than those for water samples. Among various groups of substances, the highest frequencies were observed for trace elements, followed by PCB's, chlorinated benzenes, organo-chlorine pesticides and polyaromatic hydrocarbons.

The highest annual loading was calculated for trace elements - about 420 tonnes/yr for the whole drainage basin. Among the individual elements, the highest loadings were found for zinc (68% of the total), followed by lead (20%), copper (4%), and nickel (3%).

The next highest loading was found for polyaromatic hydrocarbons - about 7.7 tonnes/yr. This estimate contains large uncertainties which are caused by the relatively high detection limits for PAH's and the resulting low frequency of occurrence above the detection limits. Improvements in the accuracy of this estimate would be possible only through further field work and the use of analytical procedures with lower detection limits.

The annual loadings of the remaining three groups are quite comparable - 77 kg/yr of PCB's, 59 kg/yr of chlorinated benzenes and 34 kg/yr of organochlorine pesticides.

If the study methodology may be extended to the undeveloped land under the municipal jurisdiction, additional loadings of 980 tonnes/yr of trace elements, 20 tonnes/yr of PAH's, 108 kg/yr of chlorinated benzenes and 60 kg/yr of organochlorine pesticides should be added to the loadings presented earlier for the fully developed urban land which is characterized by residential, commercial and industrial land use.

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TABLE 1. Population of Urban Centres in the Study Area

	Lake Sub-Basin					Total
	Erie	Huron	Ontario	St. Clair	Superior	
Population of Urban Centres	834,000	589,000	4,333,000	419,000	112,000	6,287,000
Percent of Total	13.3	9.4	68.9	6.6	1.8	100.0

TABLE 2. Summary of the Field Program

	Number of Sampling Sites	Land Use Types
Burlington	2	C ¹ , I ²
Cornwall	8	C, I, Inst ³ , R ⁴
Fort Erie	2	I
Guelph	4	C, R
Hamilton	11	C, I, R
Kingston	5	C, R
Niagara Falls	4	I, R
Ottawa	6	C, R
Sarnia	14	C, I, R
Stratford	4	C, I, R
Toronto	12	C, I, R
Welland	9	I, R

¹C = Commercial

²I = Industrial

³Inst = Institutional

⁴R = Residential

TABLE 3. Substances Studied and Detection Limits

Substance	Detection Limit			
	Water (ppb)		Sediment (ppm)	
	IWD*	MOE**	IWD	MOE
<u>PCB's</u>				
Total polychlorinated biphenyls	0.009	0.02	0.09	0.02
<u>Organochlorine Pesticides</u>				
Hexachlor benzene	0.0004	-	0.004	-
α - BHC	0.0004	0.001	0.004	0.001
Lindane	0.0004	0.001	0.004	0.001
Heptachlor	0.0004	0.001	0.004	0.001
Aldrin	0.0004	0.001	0.004	0.001
Heptachlor epoxide	0.0004	0.001	0.004	0.001
γ - chlordane	0.0004	0.002	0.004	0.002
α - chlordane	0.0004	0.002	0.004	0.002
α - Endosulfan	0.0004	0.002	0.004	0.002
p,p' - DDE	0.0004	0.001	0.004	0.001
Dieldrin	0.0004	0.002	0.004	0.002
Endrin	0.0004	0.004	0.004	0.004
o,p' - DDT	0.0004	0.005	0.004	0.005
p,p' - TDE	0.0004	0.005	0.004	0.005
p,p' - DDT	0.0004	0.005	0.004	0.005
β - Endosulfan	0.0004	0.004	0.004	0.004
Mirex	0.0004	0.005	0.004	0.005, 0.5
Methoxychlor	0.0004	0.005	0.004	0.005
<u>Polyaromatic Hydrocarbons</u>				
Indene	0.05	-	0.05	-
1,2,3,4 tetrahydronaphthalene	0.05	-	0.05	-
2, methyl naphthalene	0.05	-	0.05	-
Quinoline	0.05	-	0.05	-
1, Methyl naphthalene	0.05	-	0.05	-
β - chloronaphthalene	0.05	-	0.05	-
Acenaphthylene	0.05	-	0.05	-
Acenaphthene	0.05	-	0.05	-
Fluorene	0.05	-	0.05	-
Phenanthrene	0.05	-	0.05	-
Fluoranthene	0.05	-	0.05	-
Pyrene	0.05	-	0.05	-

* IWD Laboratory

** MOE Laboratory

TABLE 3. (continued)

Substance	Detection Limit			
	Water (ppb)		Sediment (ppm)	
	IWD*	MOE**	IWD	MOE
<u>Chlorinated Benzenes</u>				
1,3 dichlorobenzene	0.005	-	0.05	-
1,4 dichlorobenzene	0.005	-	0.05	-
1,2 dichlorobenzene	0.005	-	0.05	-
1,3,5 trichlorobenzene	0.001	0.01	0.005	-
1,2,4 trichlorobenzene	0.001	0.01	0.005	-
1,2,3 trichlorobenzene	0.001	0.01	0.005	-
1,2,4,5 + 1,2,3,5 tetrachlorobenzene	0.001	0.01	0.005	-
1,2,3,4 tetrachlorobenzene	0.001	0.01	0.005	-
pentachlorobenzene	0.001	0.01	0.005	-
Hexachlorobenzene	0.0004	0.001	0.004	0.001
<u>Trace Elements</u>				
Arsenic	0.1	30	0.05	0.03
Cadmium	1.0***	0.2, 10	10	0.3
Copper	1.0***	10,20	10	1.0
Cobalt	1.0***	20,40	10	2.0
Chromium	1.0***	10	0.5	3.0
Lead	1.0*	60	0.5	3.0
Mercury	0.05	-	0.1	-
Nickel	1.0***	30	10,30	2.0
Selenium	0.1	1,30	0.05	0.03
Zinc	1.0	1.0	0.1	2.0

* IWD Laboratory

** MOE Laboratory

*** For several samples, the detection limit was 10 ppb

TABLE 4. Precision of Trace Element Analyses (After Ref. 20)

Trace Element	Water		Sediment	
	C_W^1	C_V^2	C_S^3	C_V
Arsenic	1.8 4.4	4.8 3.2	1.2 18	5.0 3.6
Cadmium	10	3.5	100 500	5.5 3.6
Chromium	10	2.9	100 500	7.7 5.7
Cobalt	10	1.3	100 1000	11 5.1
Copper	10	1.6	100 500	2.0 1.6
Lead	10	2.2	100 500	10 8.2
Mercury	0.07 0.55	6.0 1.0	0.6 1.6	4.0 2.0
Nickel	10	3.8	100 500	10 9.4
Selenium	0.36 3.3	8.9 3.0	0.6 1.1	5.0 2.7
Zinc	10	1.4	500 1000	7.4 5.5

1C_W = standard concentration in water samples (ppb)

2C_V = coefficient of variation in percent

3C_S = standard concentration in sediment samples (ppm)

TABLE 5. Precision and Accuracy of Selected Organochlorine Pesticide Analyses (After Ref. 1)

Pesticide	Level Added ppb	Pre-treatment	Mean Recovery ppb	Recovery %	Precision Cy %
Aldrin	0.015	No cleanup	0.010	68	25
	0.11		0.079	72	26
	0.025	Cleanup	0.017	68	20
	0.10		0.065	65	12
Lindane	0.010	No cleanup	0.0097	97	36
	0.10		0.073	73	16
	0.015	Cleanup	0.014	94	37
	0.085		0.059	70	13
Dieldrin	0.020	No cleanup	0.022	110	83
	0.13		0.110	85	21
	0.025	Cleanup	0.018	70	29
	0.13		0.084	65	20
DDT	0.040	No cleanup	0.040	100	33
	0.20		0.16	77	16
	0.030	Cleanup	0.036	120	63
	0.19		0.13	71	19

NOTE: Water samples only

TABLE 6. Best Estimates of Mean Concentrations of PCB's and Organochlorine Pesticides in Urban Runoff

Parameter	Water			Sediment		
	No. of Samples	Freq. %	Mean ppb	No. of Samples	Freq. %	Mean ppm
PCB's	121	46	0.0140	123	85	0.98
Hexachlor benzene	100	45	0.00065	110	64	0.068
α - BHC	124	98	0.0190	110	28	0.0049
Lindane	124	86	0.0065	110	18	0.0035
Heptachlor	125	6	0.00018	129	16	0.0020
Aldrin	125	1	0.00014	129	10	0.0012
Heptachlor epoxide	124	27	0.0011	110	35	0.0027
γ - chlordane	124	20	0.00079	110	35	0.021
α - chlordane	124	11	0.00042	110	18	0.025
α - Endosulfan	124	26	0.00041	110	51	0.0050
p,p' - DDE	125	19	0.00038	129	21	0.0091
Dieldrin	124	26	0.00051	110	16	0.0044
Endrin	124	23	0.00077	110	26	0.0038
o,p' - DDT	125	18	0.00032	129	18	0.012
p,p' - TDE	124	28	0.00053	125	40	0.0025
p,p' - DDT	125	22	0.00036	129	3	0.017
β - Endosulfan	124	26	0.00060	110	10	0.0010
Mirex	125	3	0.00018	129	10	0.0013
Methoxychlor	124	21	0.0015	110	12	0.0059
		A=28.1%			A=24%	

TABLE 7. Best Estimates of Mean Concentrations of Polyaromatic Hydrocarbons in Urban Runoff

Parameter	Water			Sediment		
	No. of Samples	Freq. %	Mean ppb	No. of Samples	Freq. %	Mean ppm
Indene	53	2	1.0	88	13	0.440
1,2,3,4 tetrahydro-naphthalene	53	2	1.0	88	8	0.430
2, methylnaphthalene	53	19	0.95	88	0	0.460
Quinoline	53	4	1.0	88	17	0.530
1, methylnaphthalene	53	9	0.99	88	1	0.490
β - chloronaphthalene	53	15	0.97	88	3	0.440
Acenaphthylene	53	17	0.96	88	10	0.700
Acenaphthene	53	13	0.97	88	1	0.450
Flourene	53	2	1.0	88	8	0.490
Phenanthrene	53	6	1.0	88	30	1.700
Flouranthene	53	13	1.0	87	37	2.400
Pyrene	48	17	1.0	86	28	2.200

TABLE 8. Best Estimates of Mean Concentrations of Chlorinated Benzenes in Urban Runoff

Parameter	Water			Sediment		
	No. of Samples	Freq. %	Mean ppb	No. of Samples	Freq. %	Mean ppm
1,3 dichlorobenzene	100	18	0.0074	99	11	0.027
1,4 dichlorobenzene	100	25	0.0089	99	13	0.040
1,2 dichlorobenzene	100	48	0.0390	99	26	0.120
1,3,5 trichlorobenzene	122	15	0.00099	99	30	0.019
1,2,4 trichlorobenzene	122	21	0.0015	99	31	0.0085
1,2,3 trichlorobenzene	122	5	0.00084	99	21	0.0076
1,2,4,5 + 1,2,3,5 tetrachlorobenzene	122	9	0.00084	99	19	0.0050
1,2,3,4 tetrachlorobenzene	122	4	0.00082	99	17	0.0044
pentachlorobenzene	122	14	0.0010	99	53	0.0098
hexachlorobenzene	125	19	0.00073	112	50	0.075

TABLE 9. Best Estimates of Mean Concentrations of Trace Elements in Urban Runoff

Trace Element	Water			Sediment		
	No. of Samples	Freq. %	Mean ppb	No. of Samples	Freq. %	Mean ppm
Arsenic	83	87	1.7	43	100	8.2
Cadmium	104	12	1.3	112	70	2.0
Copper	105	93	19	112	94	67.0
Cobalt	90	27	2.7	43	58	11.0
Chromium	61	44	6.4	112	91	110.0
Lead	105	78	90	112	94	470.0
Mercury	95	66	3.4	100	80	0.240
Nickel	104	87	16	111	88	50.0
Selenium	83	86	1.6	32	84	0.330
Zinc	105	98	440	112	100	400.0

TABLE 10. Volumetric Runoff Coefficients for Various Land Use

Land Use	Runoff Coefficient	
	Selected	Range
Residential	0.35	0.30 - 0.50
Commercial	0.90	0.70 - 0.95
Industrial	0.70	0.60 - 0.90
Open	0.10	0.10 - 0.25

TABLE 11. Annual Urban Runoff Volumes in the Great Lakes Basin

Land Use	Sub-Basin Annual Urban Runoff Volumes (10^6 m^3)				
	Erie	Huron	Ontario	St. Clair	Superior
Residential	52.0	42.0	210	30.8	5.2
Commercial	12.1	10.2	46.2	7.1	1.2
Industrial	26.0	20.9	105	15.4	2.6
Subtotal	90.1	73.1	361.2	53.3	9.0
Open Land	370	472	673	112	21.2
Basin Totals	460	545	1030	166	30.3

TABLE 12. Annual Unit Solids Loadings in Urban Runoff for Various Land Use

Land Use	Unit Solids Loading (kg/ha)
Residential	390
Commercial	560
Industrial	672
Open	11.2

TABLE 13. Annual Solids Loadings in Urban Runoff in the Great Lakes Basin

Land Use	Sub-Basin Annual Solids loadings (tonnes)				
	Erie	Huron	Ontario	St. Clair	Superior
Residential	6650	5270	28500	3810	813
Commercial	852	701	3480	486	101
Industrial	2850	2260	12300	1630	350
Subtotal	10352	8231	44280	5926	1264
Open Land	4550	6030	8920	1450	331
Basin Totals	14900	14300	53100	7380	1590

TABLE 14. Annual Loadings of PCB's and Organochlorine Pesticides in Urban Runoff in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
Total PCB's	11.4	9.1	48.5	6.6	1.4	77.0
Organochlorine Pesticides						
Hexachlor-benzene	0.763	0.607	3.246	0.438	0.092	5.2
α - BHC	1.763	1.429	7.080	1.042	0.177	11.5
Lindane	0.622	0.504	2.503	0.367	0.063	4.1
Heptachlor	0.037	0.030	0.154	0.021	0.004	0.3
Aldrin	0.025	0.020	0.104	0.015	0.003	0.2
Heptachlor epoxide	0.127	0.103	0.517	0.075	0.013	0.8
γ - chlordane	0.289	0.231	1.215	0.167	0.034	1.9
α - chlordane	0.297	0.236	1.259	0.171	0.035	2.0
α - Endosulfan	0.089	0.071	0.369	0.051	0.010	0.6
p,p' - DDE	0.128	0.103	0.540	0.074	0.015	0.9
Dieldrin	0.091	0.073	0.379	0.053	0.010	0.6
Endrin	0.109	0.088	0.446	0.064	0.012	0.7
o,p' - DDT	0.153	0.122	0.647	0.088	0.018	1.0
p,p' - TDE	0.074	0.059	0.302	0.043	0.008	0.5
p,p' - DDT	0.208	0.166	0.883	0.120	0.025	1.4
β - Endosulfan	0.064	0.052	0.261	0.038	0.007	0.4
Mirex	0.030	0.024	0.123	0.017	0.003	0.2
Methoxychlor	0.196	0.158	0.803	0.115	0.021	1.3
Total Organochlorine Pesticides	5.1	4.1	20.8	3.0	0.6	33.6

TABLE 15. Annual Loadings of Polyaromatic Hydrocarbons in Urban Runoff in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
Indene	95	77	381	56	9	618
1,2,3,4 tetrahydro-naphthalene	95	77	380	56	9	617
2, methyl naphthalene	90	73	364	54	9	590
Quinoline	96	77	385	56	10	624
1, methyl naphthalene	94	76	379	56	10	615
β - chloronaphthalene	92	75	370	54	9	600
Acenaphthylene	94	76	378	55	9	612
Acenaphthene	92	75	370	55	9	601
Flourene	95	77	383	56	10	621
Phenanthrene	108	87	437	63	11	706
Flouranthene	115	93	467	68	12	755
Pyrene	113	91	459	66	12	741
Total PAH's	1179	954	4753	695	119	7700

TABLE 16. Annual Loadings of Chlorinated Benzenes in Urban Runoff in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
1,3 dichlorobenzene	0.946	0.763	3.868	0.554	0.101	6.2
1,4 dichlorobenzene	1.216	0.980	4.986	0.711	0.131	8.0
1,2 dichlorobenzene	4.756	3.839	19.400	2.790	0.503	31.3
1,3,5 trichlorobenzene	0.286	0.229	1.199	0.165	0.033	1.9
1,2,4 trichlorobenzene	0.223	0.180	0.918	0.130	0.024	1.5
1,2,3 trichlorobenzene	0.154	0.124	0.640	0.090	0.017	1.0
1,2,4,5 + 1,2,3,5 tetrachlorobenzene	0.127	0.103	0.525	0.074	0.014	0.8
1,2,3,4 tetrachlorobenzene	0.119	0.096	0.491	0.070	0.013	0.8
pentachlorobenzene	0.192	0.154	0.795	0.111	0.021	1.3
hexachlorobenzene	0.842	0.671	3.585	0.483	0.101	5.7
Total CB's	8.9	7.1	36.4	5.2	0.9	58.5

TABLE 17. Annual Loadings of Trace Elements in Urban Runoff in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
Arsenic	238	192	977	139	26	1600
Cadmium	138	111	558	81	14	900
Copper	2405	1940	9830	1410	256	15800
Cobalt	357	288	1462	209	38	2400
Chromium	1715	1373	7182	993	197	11500
Lead	12974	10448	53320	7582	1404	85700
Mercury	309	251	1239	183	31	2000
Nickel	1959	1581	7993	1149	207	12900
Selenium	148	120	593	87	15	1000
Zinc	43785	35456	176640	25822	4466	286200
Total Trace Elements	64000	51800	259800	37700	6700	420000

APPENDIX

TABLE A.1. Lake Erie Basin - Background Data for Calculation of
Toxics Loadings

Urban Centre Municipality	Population	Annual Precip. (mm/yr)	Annual Runoff Volume ($10^3 \text{ m}^3/\text{yr}$)		Annual Solids Loading (tonnes/yr)	
			Fully Urbanized Land*	Open Land**	Fully Urbanized Land*	Open Land**
Amherstburg	5680	843	858	88	100	1
Aylmer	5250	967	919	291	93	3
Brantford	74300	746	6620	3680	890	55
Cambridge	77200	899	8250	16700	915	105
Delhi	15100	935	2200	49200	231	589
Dunnville	11400	905	1700	27000	181	334
Fergus	6060	880	944	1340	106	5
Guelph	71200	833	7160	4140	859	55
Halimand	16900	907	2300	57400	254	708
Kingsville	5130	812	755	185	92	2
Kitchener	140000	897	13590	9110	1517	113
Leamington	12500	816	1624	356	197	4
Nanticoke	19800	948	2700	63400	292	748
Norfolk	11200	907	1700	62200	180	768
Paris	7480	782	1005	615	126	8
Port Colborne	19200	985	2800	11500	284	130
Simcoe	14300	911	2030	3240	221	39
St. Thomas	28200	912	3585	865	392	10
Tillsonburg	10500	914	1560	1450	169	17
Waterloo	49400	895	5660	4540	631	56
West Sandwich- Township	13800	849	1820	5170	215	68
Wilmot	10900	932	1600	24100	175	289
Windsor	192000	849	16750	6450	1985	85
Woolwich	16500	807	2000	25700	248	356

* Includes residential, institutional, commercial and industrial land

** Includes undeveloped land

TABLE A.2. Lake Huron Basin - Background Data for Calculation of Toxics Loadings

Urban Centre Municipality	Population	Annual Precip. (mm/yr)	Annual Runoff Volume ($10^3 \text{ m}^3/\text{yr}$)		Annual Solids Loading (tonnes/yr)	
			Fully Urbanized Land*	Open Land**	Fully Urbanized Land*	Open Land**
Aurora	16300	792	1950	3620	245	51
Barrie	38400	950	4850	1680	511	19
Bradford	7370	716	908	332	125	5
Collingwood	12100	858	1660	1450	191	18
East Gwillimbury	12600	757	1500	18200	198	269
Elliot Lake	16700	926	2300	69600	249	841
Essa	13800	832	1800	23200	215	311
Espanola	5840	861	890	1340	103	17
Georgina Township	20100	872	2600	24400	295	313
Goderich	7320	926	1171	339	125	4
Hanover	6320	878	972	358	110	4
Huntsville	11500	971	1800	67700	183	780
Innisfil	16800	879	2200	24500	253	312
Kincardine	5780	963	999	521	102	6
Listowel	5030	951	874	396	90	4
Midland	12100	1030	2000	1220	193	13
Newmarket	29800	797	3280	2180	411	30
Nickel Centre	12300	827	1600	31000	194	419
North Bay	51300	947	6200	28200	652	333
Orillia	24000	907	3110	1390	342	17
Owen Sound	19900	1020	3010	1370	292	15
Parry Sound	6120	1090	1190	1380	108	14
Penetanguishene	5320	1030	999	681	95	7
Port Elgin	6130	866	937	323	108	4
Rayside-Balfour	15000	827	1900	26700	230	361
Sault St. Marie	82700	898	8700	18000	977	223
Sturgeon Falls	6040	887	955	305	106	3
Sudbury	91800	827	8800	19800	1063	267
Valley East	20400	827	2500	42400	299	574
Walden	10100	827	1400	59100	165	800

* Includes residential, institutional, commercial and industrial land

** Includes undeveloped land

TABLE A.3. Lake Ontario Basin - Background Data for Calculation of Toxics Loadings

Urban Centre Municipality	Population	Annual Precip. (mm/yr)	Annual Runoff Volume ($10^3 \text{ m}^3/\text{yr}$)		Annual Solids Loading (tonnes/yr)	
			Fully Urbanized Land*	Open Land**	Fully Urbanized Land*	Open Land**
Ajax	25500	840	3030	5020	361	66
Ancaster	14400	824	1800	14000	222	190
Belleville	34900	855	4020	1170	470	15
Brampton	149000	816	13000	18700	1603	257
Burlington	115000	795	10200	11800	1284	166
Caledon	26600	789	3000	53500	371	759
Cobourg	11400	822	1500	630	181	8
Dundas	19600	824	2380	1480	288	20
East York, Toronto	102000	736	6790	0	958	0
Ernestown	11400	867	1600	22700	182	292
Etobicoke, Toronto	299000	757	21630	4570	2883	67
Flamborough	24500	824	2900	39700	349	540
Fort Erie	24100	995	3400	16000	343	179
Grimsby	15800	876	2110	5500	240	70
Halton Hills	35200	823	3900	21800	475	297
Hamilton	306000	829	24200	4800	2946	64
Kingston	52600	900	5980	7260	666	15
Kingston- Township	28000	867	3400	17400	390	224
King-Township	15200	808	1800	26400	231	365
Lincoln	14200	894	1900	14200	219	177
Lindsay	13600	856	1824	906	212	11
Markham	77000	795	7300	15200	917	213
Milton	28100	875	3400	31400	392	401
Mississauga	315000	867	25900	18000	3008	232
Newcastle	32200	942	4200	56300	440	670
Niagara Falls	71000	936	8000	18100	854	216
Niagara-on- the-Lake	12200	837	1600	10600	193	142
North York, Toronto	559999	802	38880	5520	4893	77
Oakville	75800	799	7260	9440	908	132
Orangeville	13700	816	1743	707	213	9
Oshawa	118000	864	11310	9890	1312	128
Pelham	11100	962	1700	11600	179	135
Peterborough	60600	793	5940	2910	751	41

Continued...../

TABLE A.3. (cont'd)

Urban Centre Municipality	Population	Annual Precip. (mm/yr)	Annual Runoff Volume ($10^3 \text{ m}^3/\text{yr}$)		Annual Solids Loading (tonnes/yr)	
			Fully Urbanized Land*	Open Land**	Fully Urbanized Land*	Open Land**
Pickering	37800	773	3800	16700	503	241
Port Hope	9990	801	1309	511	163	7
Richmond Hill	37800	805	4060	7240	503	100
Scarborough,	442999	807	32110	7990	4020	110
Toronto						
Scugog-Township	13500	851	1800	39000	210	513
Sidney-Township	16100	856	2100	23400	244	306
Stoney Creek	36800	876	4310	7690	492	98
St. Catharines	124000	807	11020	5180	1369	71
Thorold	15400	872	2050	6920	234	88
Toronto	598999	800	33700	0	4380	0
Trenton	15100	855	1990	540	231	7
Uxbridge	11200	788	1400	32500	180	461
Vaughan	29700	774	3200	20600	410	298
Welland	45400	938	5500	6400	588	76
Whitby	36700	813	4000	10700	492	147
Whitchurch-	13600	806	1700	16000	211	221
Stouffville						
York, Toronto	135000	787	7700	0	1040	0

* Includes residential, institutional, commercial and industrial land

** Includes undeveloped land

TABLE A.4. Lake St. Clair Basin - Background Data for Calculation of Toxics Loadings

Urban Centre Municipality	Population	Annual Precip. (mm/yr)	Annual Runoff Volume ($10^3 \text{ m}^3/\text{yr}$)		Annual Solids Loading (tonnes/yr)	
			Fully Urbanized Land*	Open Land**	Fully Urbanized Land*	Open Land**
Chatham	41000	808	4341	879	538	12
Essex	6290	843	931	339	110	4
Gosfield- Township	11200	828	1500	19600	180	264
Ingersoll	8490	900	1290	630	141	7
London	254000	935	23320	9980	2511	119
Moore-Township	10000	778	1200	23300	164	334
Norwich	9770	913	1500	39200	160	480
Sarnia	50900	890	5760	1640	647	20
Sarnia- Township	20200	882	2700	12300	295	156
Stratford	26300	1030	3820	1250	370	13
Strathroy	8750	894	1307	953	145	11
Tecumseh	6360	849	944	316	111	4
Wallaceburgh	11500	760	1403	487	183	7
Woodstock	26600	862	3230	1390	373	18

* Includes residential, institutional, commercial and industrial land

** Includes undeveloped land

TABLE A.5. Lake Superior Basin - Background Data for Calculation of Toxics Loadings

Urban Centre Municipality	Population	Annual Precip. (mm/yr)	Annual Runoff Volume ($10^3 \text{ m}^3/\text{yr}$)		Annual Solids Loading (tonnes/yr)	
			Fully Urbanized Land*	Open Land**	Fully Urbanized Land*	Open Land**
Thunder Bay	112000	718	9100	21200	1259	331

* Includes residential, institutional, commercial and industrial land
 ** Includes undeveloped land

TABLE A.6. Lower and Upper Estimates of Mean Concentrations of PCB's and Organochlorine Pesticides in Urban Runoff

Parameter	Water		Sediment	
	Lower Estimate (ppb)	Upper Estimate (ppb)	Lower Estimate (ppm)	Upper Estimate (ppm)
PCB's	.01231	.01654	.9787	.9867
Hexachlor benzene	.00056	.00073	.0680	.0688
α - BHC	.01866	.01900	.0043	.0055
Lindane	.00648	.00653	.0027	.0043
Heptachlor	.00005	.00031	.0012	.0028
Aldrin	.000004	.00028	.0004	.0021
Heptachlor epoxide	.00095	.00116	.0018	.0035
γ - chlordane	.00066	.00092	.0202	.0214
α - chlordane	.00028	.00055	.0242	.0254
α - Endosulfan	.00029	.00053	.0041	.0058
p,p' - DDE	.00025	.00050	.0086	.0095
Dieldrin	.00039	.00064	.0036	.0053
Endrin	.00063	.00092	.0029	.0047
o,p' - DDT	.00016	.00048	.0118	.0132
p,p' - TDE	.00039	.00067	.0017	.0032
p,p' - DDT	.00020	.00052	.0161	.0172
β - Endosulfan	.00047	.00073	.0001	.0020
Mirex	.00001	.00035	.0004	.0022
Methoxychlor	.00132	.00161	.0050	.0068

TABLE A.7. Lower and Upper Estimates of Mean Concentrations of Polyaromatic Hydrocarbons in Urban Runoff

Parameter	Water		Sediment	
	Lower Estimate (ppb)	Upper Estimate (ppb)	Lower Estimate (ppm)	Upper Estimate (ppm)
Indene	.0002	2.0568	.043	.832
1,2,3,4 tetrahydro-naphthalene	.0002	2.0568	.012	.846
2, methyl-naphthalene	.0074	1.8942	.000	.914
Quinoline	.0009	2.0387	.155	.899
1, methyl-naphthalene	.0034	1.9845	.036	.939
β - chloronaphthalene	.0062	1.9308	.003	.883
Acenaphthylene	.0113	1.9170	.298	1.110
Acenaphthene	.0023	1.9457	.003	.906
Flourene	.0002	2.0568	.075	.903
Phenanthrene	.0042	2.0230	1.355	1.984
Flouranthene	.0532	1.9966	2.077	2.639
Pyrene	.0071	2.0279	1.856	2.515

TABLE A.8. Lower and Upper Estimates of Mean Concentrations of Chlorinated Benzenes in Urban Runoff

Parameter	Water		Sediment	
	Lower Estimate (ppb)	Upper Estimate (ppb)	Lower Estimate (ppm)	Upper Estimate (ppm)
1,3 dichlorobenzene	.0016	.0132	.0045	.0485
1,4 dichlorobenzene	.0038	.0140	.0182	.0612
1,2 dichlorobenzene	.0348	.0432	.0972	.1341
1,3,5 trichlorobenzene	.0003	.0017	.0177	.0211
1,2,4 trichlorobenzene	.0009	.0021	.0068	.0102
1,2,3 trichlorobenzene	.0001	.0016	.0056	.0096
1,2,4,5 + 1,2,3,5 tetrachlorobenzene	.0001	.0016	.0029	.0070
1,2,3,4 tetrachlorobenzene	.00004	.0016	.0023	.0064
pentachlorobenzene	.0003	.0017	.0086	.0110
hexachlorobenzene	.0003	.0012	.0740	.0762

TABLE A.9. Lower and Upper Estimates of Mean Concentrations of Trace Elements in Urban Runoff

Trace Element	Water		Sediment	
	Lower Estimate (ppb)	Upper Estimate (ppb)	Lower Estimate (ppm)	Upper Estimate (ppm)
Arsenic	.601	2.799	8.160	8.160
Cadmium	.352	2.181	.776	3.281
Copper	18.371	19.141	67.036	67.042
Cobalt	.789	4.678	8.474	12.660
Chromium	5.295	7.475	106.102	106.229
Lead	88.800	91.695	465.023	466.822
Mercury	3.425	3.442	.226	.246
Nickel	14.837	16.904	48.680	50.932
Selenium	.611	2.500	.325	.341
Zinc	441.800	441.819	400.643	400.643

TABLE A.10. Loadings Calculated for Lower and Upper Estimates of Mean Toxic Concentrations

Parameter	Type of Estimate	Sub-Basin Annual Loading (kg/yr)					Whole Basin Loading (kg/yr)
		Erie	Huron	Ontario	St. Clair	Superior	
Total PCB's	Lower ¹	11.2	9.0	47.8	6.5	1.4	75.8
	Best ²	11.4	9.1	48.5	6.6	1.4	77.0
	Upper ³	11.7	9.3	49.7	6.7	1.4	78.8
Total Organo-chlorine Pesticides	Lower	4.7	3.8	19.3	2.7	0.5	31.0
	Best	5.1	4.1	20.8	3.0	0.6	33.6
	Upper	5.4	4.3	22.2	3.2	0.6	35.7
Total PAH's	Lower	70	56	297	40	8	471
	Best	1179	954	4753	695	119	7700
	Upper	2315	1876	9324	1367	235	15116
Chlorinated Benzenes	Lower	6.3	5.0	25.8	3.7	0.7	41.5
	Best	8.9	7.1	36.4	5.2	0.9	58.5
	Upper	11.4	9.2	46.6	6.7	1.2	75.1
Total Trace Elements	Lower	63240	51120	256600	37200	6570	414700
	Best	64000	51800	259800	37700	6700	420000
	Upper	64950	52510	263500	38200	6750	425900

- ¹ Based on the lower estimate of mean concentrations from eq. (9)
² Based on the best estimate of mean concentrations from eq. (11)
³ Based on the upper estimate of mean concentrations from eq. (10)

TABLE A.11. Annual Loadings of PCB's and Organochlorine Pesticides in Runoff from Land Under Municipal Jurisdiction in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
Total PCB's	21.0	21.6	66.5	9.6	2.0	120.7
Organochlorine Pesticides						
Hexachlor-benzene	1.31	1.33	4.28	.61	.13	7.7
α - BHC	8.81	10.43	19.83	3.19	.58	42.8
Lindane	3.04	3.59	6.88	1.10	.20	14.8
Heptachlor	.11	.13	.29	.04	.01	.6
Aldrin	.08	.09	.21	.03	.01	.4
Heptachlor epoxide	.55	.64	1.28	.20	.04	2.7
γ - chlordane	.68	.73	1.93	.29	.06	3.7
α - chlordane	.57	.59	1.76	.25	.05	3.2
α - Endosulfan	.26	.29	.69	.10	.02	1.4
p,p' - DDE	.31	.34	.87	.13	.03	1.7
Dieldrin	.30	.34	.76	.11	.02	1.5
Endrin	.41	.47	.99	.16	.03	2.1
o,p' - DDT	.33	.35	.97	.14	.03	1.8
p,p' - TDE	.28	.32	.68	.11	.02	1.4
p,p' - DDT	.42	.44	1.27	.19	.04	2.4
β - Endosulfan	.29	.34	.67	.11	.02	1.4
Mirex	.10	.12	.25	.04	.01	.5
Methoxychlor	.78	.90	1.86	.29	.05	3.9
Total Organochlorine Pesticides	18.63	21.44	45.47	7.09	1.35	94.0

TABLE A.12. Annual Loadings of Polyaromatic Hydrocarbons in Runoff from Land Under Municipal Jurisdiction in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
Indene	467	551	1053	169	31	2271
1,2,3,4 tetrahydro-naphthalene	466	551	1053	169	31	2270
2, methyl-naphthalene	444	524	1003	161	29	2161
Quinoline	468	553	1058	170	31	2279
1, methyl-naphthalene	463	547	1046	168	30	2253
β - chloronaphthalene	453	535	1022	164	30	2204
Acenaphthylene	452	533	1026	165	30	2206
Acenaphthene	453	535	1023	164	30	2205
Flourene	467	552	1056	170	31	2276
Phenanthrene	485	569	1120	179	33	2386
Flouranthene	496	579	1157	184	34	2450
Pyrene	493	576	1147	182	33	2432
Total PAH's	5607	6605	12764	2045	373	27400

TABLE A.13. Annual Loadings of Chlorinated Benzenes in Runoff from Land Under Municipal Jurisdiction in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
1,3 dichlorobenzene	3.81	4.42	9.06	1.43	.26	19.0
1,4 dichlorobenzene	4.69	5.42	11.29	1.77	.33	23.5
1,2 dichlorobenzene	19.73	22.97	46.54	7.36	1.36	98.0
1,3,5 trichlorobenzene	.74	.81	2.03	.30	.06	3.9
1,2,4 trichlorobenzene	.82	.94	2.00	.31	.06	4.1
1,2,3 trichlorobenzene	.50	.57	1.27	.20	.04	2.6
1,2,4,5 + 1,2,3,5 tetrachlorobenzene	.46	.53	1.13	.18	.03	2.3
1,2,3,4 tetrachlorobenzene	.44	.51	1.08	.17	.03	2.2
pentachlorobenzene	.61	.69	1.55	.24	.05	3.1
hexachlorobenzene	1.45	1.47	4.73	.67	.14	8.5
Total CB's	33.25	38.33	80.68	12.63	2.36	167

TABLE A.14. Annual Loadings of Trace Elements in Runoff from Land Under Municipal Jurisdiction in the Great Lakes Basin

Parameter	Sub-Basin Annual Loadings (kg/yr)					Whole Basin Loading (kg/yr)
	Erie	Huron	Ontario	St. Clair	Superior	
Arsenic	904	1044	2186	343	64	4500
Cadmium	628	737	1445	231	42	3100
Copper	9738	11313	23128	3648	677	48500
Cobalt	1406	1629	3365	529	98	7000
Chromium	4583	5061	12433	1874	367	24300
Lead	48403	55771	117657	18409	3447	243700
Mercury	1568	1856	3515	566	102	7600
Nickel	8105	9435	19135	3025	560	40300
Selenium	741	877	1666	268	49	3600
Zinc	208360	245520	474440	75992	13836	1018100
Total Trace Elements	284400	333200	659000	104900	19200	1401000

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LOADINGS OF SELECTED TOXIC SUBSTANCES IN
THE CANADIAN GREAT LAKES BASIN. / Marsal
Loadings of selected toxic substances in
in the Canadian Great Lakes basin.

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